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Energy sustainability indicators for local energy planning: Review of current practices and derivation of a new framework

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ABSTRACT

Tackling climate change is a growing concern of our society. Although action is needed at all levels of governance, local authorities play a key role in climate action. The creation of sustainable energy and climate action plans at the local level are recent trends that show increasing local commitment. During the last decade, several municipalities have started to develop plans, but surprisingly little systematic technical guidance has been provided to them. As part of an effort to develop tools to assist energy planning at the local level, this study addresses the role of indicators in energy planning. This paper aims to propose a framework of local energy sustainability indicators to be used both as an assessment and as an action-planning tool. A literature review of existing sets of sustainability indicators and the testing of the selected indicators with pilot municipalities has led to a framework composed by 18 indicators. The indicators proposed were developed by having into consideration, besides relevance, their potential use as decision criteria for identifying the most effective actions for local energy planning. The paper also investigates the presence of the proposed indicators in existing local sustainability assessment initiatives and energy and climate action plans as well as the purpose for which they were being used in the plans. The analysis of 10 local energy and climate action plans has revealed that local authorities are using indicators mostly for diagnosis purposes, paying less attention to monitoring. Using indicators as decision criteria to choose the actions to be included in the action plan is not yet a common practice. It was also found that only a small number of the indicators proposed in this paper were already considered in the action plans analysed.

Contents

1. Introduction

Energy systems of today are largely driven by the combustion of fossil fuels. The emissions of greenhouse gases (GHG), the depletion of natural resources and the risks on the security of energy supply are the major consequences of the demand of fossil fuels. Associated emissions of GHG of intensive energy use are considered to be the principal cause of climate change. Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1970 [1].

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The main challenge is to take action to tackle climate change, and this requires a shift away from the current fossil fuel-based energy paradigm. There is a need to use less primary energy to provide the same or increased energy service, and to use energy from sustainable energy sources. A new energy paradigm is emerging, where centralized energy supply based on large scale production of fuels and electricity is replaced by a decentralized energy management approach. This paradigm shift constitutes a major energy policy challenge and requires action at different levels of governance.

Local authorities are expected to be a key player in the fight against climate change. In fact, the "global" problem of climate change has its roots in the intensive use of energy, which is in turn used "locally" to sustain local activities. Agenda 21, the global action plan for Sustainable Development for the 21st Century highlights the need to "think globally, act locally" [2]. The Aalborg Charter emphasizes the capacity of local authorities to solve some of the global environmental problems, as they are close to where environmental problems are perceived and closest to the citizens [3].

The role of local authorities in tackling climate change can be traced in the emerging local sustainable energy and climate action plans. Recent trends are initiatives, such as the C40 Cities [4] and the Covenant of Mayors [5], stressing the fact that cities are important actors for implementing sustainable energy policies and that their actions must be encouraged and supported. Local authorities are striving for making part of climate action. They advocate for empowerment of their roles in the fight against climate change such as through the Local Government Climate Roadmap [6]. But surprisingly, there have been few technical support tools to provide guidance on how local authorities should develop their energy and climate action plans. This is contrary to what happens in other areas of energy planning, such as renewable energy planning, energy resource allocation, transportation energy management or electric utility planning, where sophisticated decision-support techniques have been developed over time [7].

Of particular interest to this study is the role of indicators in the assessment of energy sustainability and in energy planning processes at the level of municipalities. Given the wide commitment to sustainable development, it becomes imperative to assess progress towards the achievement of the goals and targets established. But indicators can be also a potential key-part of planning processes, if they (i.e. their projected values in different alternative futures) are used as decision criteria in the choice of actions to be implemented. Previous work has been relatively limited in providing comprehensive sets of energy sustainability indicators to be used at the local level. The development of national level sustainability indicators is a well documented work [8–12] as it is for energy indicators [13,14]. However, a review of local sustainability initiatives shows that they still lack comprehensive and systematic sets to assess energy sustainability [15–18].

This paper aims to propose a framework of indicators for local energy sustainability assessment to be used in the process of energy planning at the local level. The research question focuses on which framework of indicators does better translate a comprehensive and meaningful assessment of energy sustainability. In order to answer this question, it was necessary to conduct a literature review of existing sets of sustainable development and energy indicators and to test the selected indicators with pilot municipalities. The methodology adopted has led to the identification of a framework of 18 local energy sustainability indicators.

The paper also aims to investigate the presence of the proposed indicators in existing local sustainability assessment initiatives and energy and climate action plans as well as the purpose for what they are being used (benchmarking, diagnosis, decision-making and monitoring).

2. The concept of local energy sustainability

Energy contributes to the satisfaction of human needs and aspirations, the major objective of development. The variety of energy services provided by energy resources is enormous, leading to access commodities that improve the human welfare. However, the chain that delivers the energy services to the consumers and the way they make use of it produces, in the current energy paradigm, negative effects on the ecosystems, such as the depletion of natural resources and the emissions of GHG.

An energy system which reduces the side effects on the environment to a level within its assimilative capacity, and which raises opportunities for economic and social development, taking a longer-term perspective, forms the basis of the concept of energy sustainability. The three dimensions of sustainable development must therefore be fulfilled simultaneously at the local level:

- *Environmental:* by reducing the side effects caused by the energy supply chain and inefficient energy use: GHG emissions, air pollution and depletion of the natural resources;
- *Economic:* by reducing energy dependence and by enabling the activities that generate business and wealth, e.g. by increasing local business investment in renewable energy and energy efficiency;
- *Social:* by improving human health, creating jobs and involving the citizens in decision-making processes.

The territorial dimension of the concept in which this paper focuses is the local level. Particularly, the concept is applied to municipalities, a low level administrative division of a country. Thus, it becomes necessary to define the boundaries of evaluation of local energy sustainability. Economic and social dimensions are here evaluated within the territorial administration of municipalities. Environmental impacts from energy production and use cannot be limited to the territory of the municipality. An energy chain encompasses energy resources extraction, transformation, distribution, use and by-products. Generally, the municipality imports energy from the State or the Country grid. There are only a few municipalities where energy transformation infrastructures are located within their boundaries. Thus, the question is how the environmental impacts such as GHG emissions at the main transformation plants should be allocated among municipalities. The municipality which has the infrastructure whose energy is incorporated into the State or Country grid cannot be held responsible for all the emissions and resources depletion. Instead, it is reasonable that the impacts should be allocated to all the municipalities. This can be done by having into account the energy use of the municipality and the composition of the State or Country energy mix.

3. Framework of local energy sustainability indicators

3.1. Methodology

The development of a framework of local energy sustainability indicators encompassed several methodological steps as shown in Fig. 1. Neves and Leal [19] present a detailed explanation of the methodological process before the testing of the calculation of the indicators (step 7). Starting by the literature review of sets of sustainability indicators [8–12,20,21,13], it was then conducted an identification of the energy-based indicators contained in the publications selected.

This first step revealed a number of indicators that were either repeated or very similar in at least two publications. These repetitions were removed from the set. Afterwards, three selection criteria were applied to the remaining indicators:

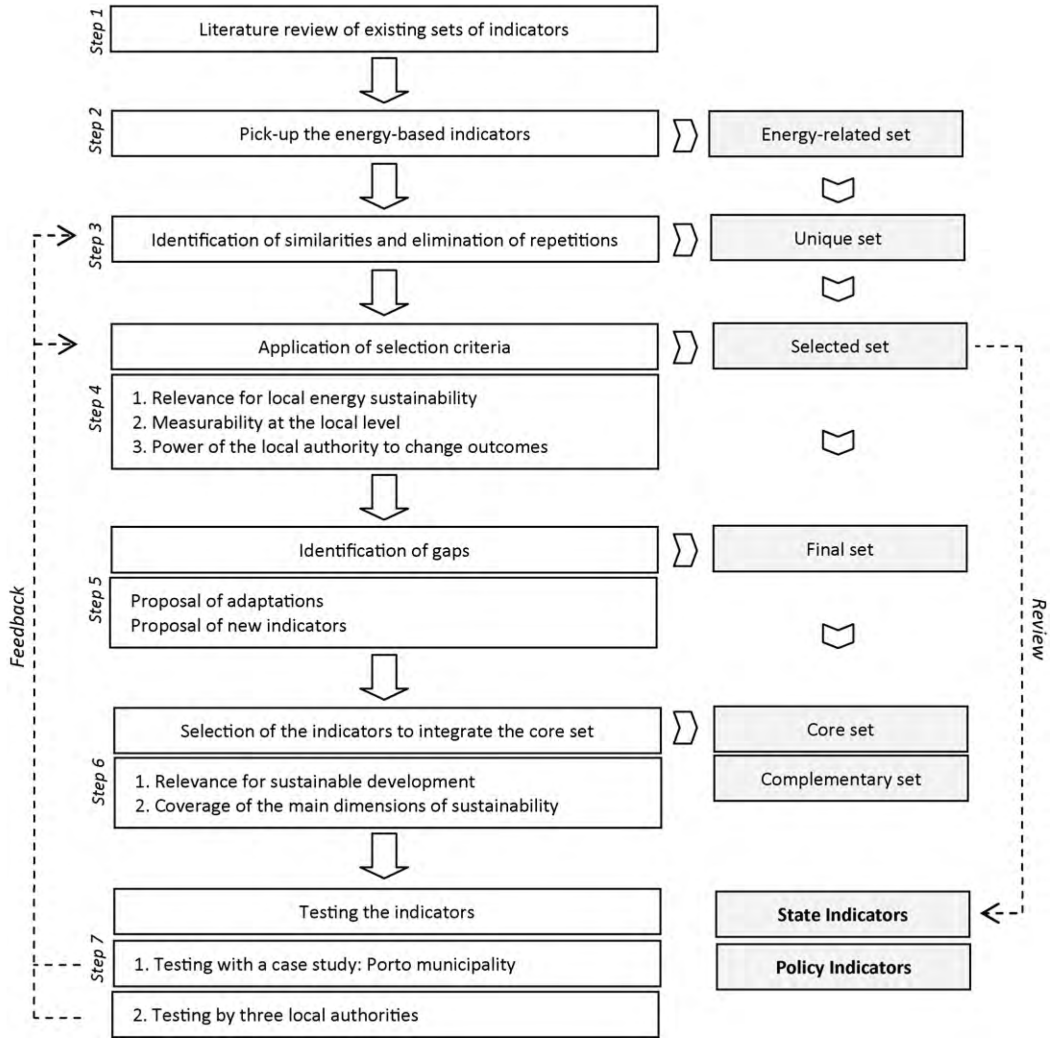


Fig. 1. Methodology adopted for the development of the framework of local energy sustainability indicators.

(1) Relevance of the indicator for local energy sustainability.
(2) Potential measurability at the local level.
(3) Power of the local authority to change the outcomes measured by the indicator.

The indicators which fulfilled simultaneously these criteria were eligible for the following step. Table 1 to be presented in Section 3.2 documents this process. The next step consisted in a critical analysis with the aim of identifying possible remaining gaps. This has led to the identification of new indicators as well as to the adaption of existing ones [19].

The set of indicators reached was still considered too large. The Bellagio Principles [22] and the United Nations Commission of Sustainable Development [8] recommend that indicators should be limited in number, but remain open-ended and adaptable to future needs. It was then decided to divide the set into a smaller and manageable set called the core set (Table 2) and a larger set named the complementary set (Table 3). The indicators that integrate the core set were chosen by their relevance for sustainable development and coverage of the three dimensions of sustainability.

Subsequently, it was conducted that the testing of the indicators which was divided into two components:

1. Calculation of the indicators for a case study: the municipality of Porto (Portugal)—The objective was to develop methods to compute the indicators and to identify the availability of data. The results of this step led to the elaboration of a methodological guide which was then distributed to the participating local authorities in component 2. The guide was composed by detailed methodological sheets for each indicator, containing data requirements and sources, calculation method and the case study example.
2. Participation of three local authorities in the calculation of the indicators for their municipalities—The local authorities were invited to calculate the indicators by using their human resources. They were asked to provide feedback regarding data gathering and practical calculation difficulties as well as perceived relevance of the indicators to local energy sustainability.

The inputs resulting from both components of the testing stage were then used to review the set of indicators, as represented in Fig. 1.

3.2. Results

Step 2 in Fig. 1 has resulted in the identification of 110 energy-based indicators. Fig. 2 shows the number of energy-based indicators (in black) in the overall number of indicators in each publication.

Table 1
Application of selection criteria to the indicators.

Indicator	Criteria		
	Relevance for local energy sustainability	Measurability at the local level	Roles of local authorities
Share of households (or population) without electricity or commercial energy	√	√	×
Share of household income spent on fuel and electricity	√	√	√
Household energy use for each income group and corresponding fuel mix	×	√	×
Accident fatalities per energy produced by fuel chain	×	×	×
Energy use per capita	√	√	√
Energy use per unit of GDP	×	√	√
Efficiency of energy conversion and distribution	×	×	×
Reserves-to-production ratio	×	×	×
Resources-to-production ratio	×	×	×
Industrial energy intensities	√	√	√
Agricultural energy intensities	√	√	√
Service/commercial energy intensities	√	√	√
Household energy intensities	√	√	√
Transport energy intensities	√	√	√
Fuel shares in energy and electricity	√	√	√
Non-carbon energy share in energy and electricity	√	√	√
Renewable energy share in energy and electricity	√	√	√
End-use energy prices by fuel and by sector	√	√	×
Net energy import dependency	×	×	×
Stocks of critical fuels per corresponding fuel consumption	×	×	×
GHG emissions from energy production and use, per capita and per unit of GDP	√	√	√
Ambient concentrations of air pollutants in urban areas	√	√	√
Air pollutant emissions from energy systems	√	√	×
Contaminant discharges in liquid effluents from energy systems	√	√	×
Oil discharges into coastal waters	√	√	×
Soil area where acidification exceeds critical load	×	×	×
Rate of deforestation attributed to energy use	√	×	√
Ratio of solid waste generation to units of energy produced	×	×	×
Ratio of solid waste properly disposed of to total generated solid waste	×	×	×
Ratio of solid radioactive waste to units of energy produced	×	×	×
Ratio of solid radioactive waste awaiting disposal to total generated solid radioactive waste	×	×	×
Average satisfaction with the local community	×	√	√
Business demography	√	√	√
Attendance at community group meetings	√	√	√
GHG emissions by sector	√	√	√
Combined heat and power generation	√	√	×
Energy consumption by transport mode	√	√	√
Access to public transport	√	√	√
External costs of transport activities	×	×	×
Emissions of air pollutants from transport activities	√	√	√
Share of major proposals with an impact assessment	√	√	×
Responses to EC internet public consultations	√	√	√
E-government on-line availability	√	√	√
E-government usage by individuals: total	×	√	√
CO_2 removed by sinks	×	×	√
External costs of energy use	×	×	×
Energy tax revenue	×	√	×
Road share of inland freight transport	×	×	×
Modal split of freight transport	×	√	×
Freight transport prices by mode	×	×	×
Investment in transport infrastructure by mode	×	√	√
Annual energy consumption, total and by main user category	√	√	√
Modal split of passenger transport	√	√	√
Percentage of population using solid fuels for cooking	√	√	×
Eco-efficiency of economic activities	×	×	×
Use of cleaner and alternative fuels	√	×	√
Projections of GHG emissions and removals and policies and measures	×	×	√
Global and European temperature	×	×	×
Atmospheric GHG concentrations	×	×	×

In step 3 (Fig. 1), the similar indicators were removed from the set. This resulted in 61 indicators. However, the first component of the testing stage in step 7 still identified repeated indicators, and during the review process the number was reduced to 59 indicators. Step 4 consisted in the application of three selection criteria. Table 1 presents these criteria applied to the 59 indicators (after a first review). The indicators that fulfilled simultaneously the criteria were selected for the following phase.

The review process resulting from the first component of the testing stage has also led to the removal of one indicator—Ambient concentration of air pollutants in the atmosphere. Discussions with experts in air quality have highlighted the difficulty of measuring this indicator at the scale of the municipality. In the case of the European Union, Directive 96/62/CE on ambient air quality assessment and management [27] obliges Member-States to the delimitation of their territory into Zones and Agglomerations that are subjected to mandatory air quality assessment. Thus, the measurement of the indicator does not coincide with the boundaries of the municipality, due to the dispersion of pollutants. Also, its relevance regarding the causal relationship energy–

Table 2
Core set of local energy sustainability indicators resulting from step 6 in Fig. 1.

Theme	Core indicators	Units
Climate change	GHG emissions from energy use, per capita and per unit of GDP	Tonnes CO_2 eq. per capita and per Euro
Use and production patterns	Primary energy use per capita	Toe (p.e.) per capita
	Annual energy consumption per capita by main use category	Toe (f.e.) per capita
	Ratio of local renewables production to local consumption of energy and electricity	%
Employment	Ratio of energy-related jobs to population	%
Financial resources	Locally available finance schemes for energy efficiency and renewable energy	% or qualitative
Air quality	Emissions of air pollutants from road transport activities	tonnes
Governance and Public engagement	Active public participation in energy-related policy-making	% or qualitative

p.e.: primary energy and f.e.: final energy.

Table 3
Complementary set of local energy sustainability indicators resulting from step 6 in Fig 1.

Theme	Complementary indicators	Units
Climate change	GHG emissions by sector	Tonnes CO_2 eq. per capita and per Euro
Use and production patterns	Industrial energy intensity	Toe (f.e.) per Euro
	Agricultural energy intensity	Toe (f.e.) per Euro
	Service/commercial energy intensity	Toe (f.e.) per Euro
	Household energy intensity	Toe (f.e.) per capita
	Transport energy intensity	Toe (f.e.) per pkm or tkm
	Energy consumption by transport mode	Toe
	Modal split of passenger transport	% of pkm
	Travel distance by mode of transport	pkm/year
	Access to public transport	%
	Fuel shares in energy and electricity	%
	Renewable energy share in energy and electricity	%
	Energy production from microgeneration projects	%
Affordability	Share of household income spent on fuel and electricity	%
Governance and public engagement	Responses to public consultations of energy-related projects	%
	E-government on-line energy-related information availability	Qualitative
	Awareness raising campaigns on energy issues	%
	Local Authority advice and assistance to the citizens on energy issues	Qualitative

p.e.: primary energy and f.e.: final energy.

environment can be questionable due to the influence of natural events.

The testing stage with the case study of Porto revealed a great difficulty in collecting data to compute the indicators. Available statistics hardly have directly the data required for the indicators. Most data difficulties have appeared in computing the transport-based indicators. The data was not available at lower levels of governance; the most common was to find it for the national level. In the absence of data, estimates had to be performed which reduce the robustness of the indicator.

In step 6, it was defined a core set composed by eight indicators and a complementary set of 18 indicators presented in Tables 2 and 3, respectively. These were the indicators used in the second component of the testing stage.

Eight Portuguese local authorities were invited to participate in the testing stage, from which two accepted: AdEPorto and AREANATejo. In the United States (US), it was made an invitation to the City of Boston which has responded affirmatively. More details on the participating local authorities can be found in Table 4.

Table 5 presents the indicators that each participant has calculated to the respective municipalities. AREANATejo has calculated the indicators for the 14 municipalities that make part of the area of action of the energy agency.

The number of indicators calculated by the participants was low. Though, this was a voluntary effort and the local authorities had to face obstacles such as the lack of staff capacity and other prior projects. In the case of the Portuguese energy agencies, the

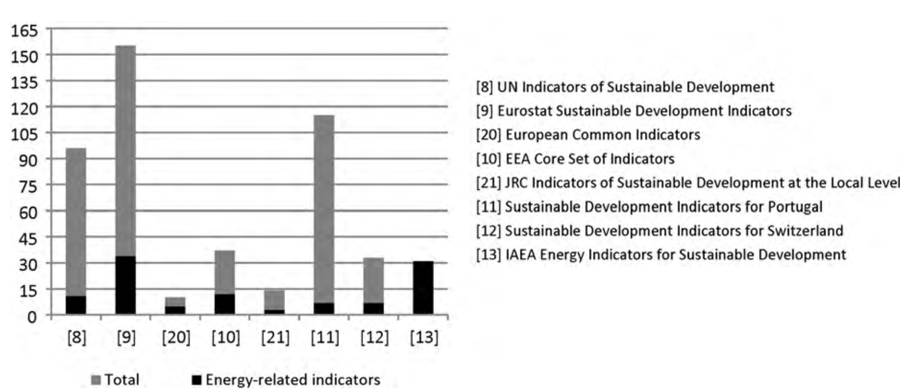


Fig. 2. Representativeness of energy-related indicators in each set of sustainable development indicators.

Table 4
Characteristics of the local authorities involved in the testing stage.

Name	Type	Municipalities	Location	Population in 2007 [23,24]	Testing period in 2009	
					Invitation	Feedback
AdEPorto	Energy agency	Porto	Second largest city in Portugal and the centre of Porto Metropolitan Area.	221,800	June	November
AREANA Tejo	Energy agency	Alter do Chão, Arrinches, Avis, Campo Maior, Castelo de Vide, Crato, Elvas, Fronteira, Gavião, Marvão, Monforte, Mora, Nisa, Portalegre, and Sousel	14 municipalities located in North Alentejo in Portugal.	Total of 106,233 which vary from 3129 in Monforte to 24,028 in Portalegre	June	September
City of Boston	City Council	Boston	Capital and largest city of the Commonwealth of Massachusetts in the US. It is the centre of Greater Boston metropolitan area.	608,352	October	January 2010

data used for the calculation of the indicators had been previously collected for the elaboration of the energy matrixes. An energy matrix is a report which contains a characterization of the energy demand and supply of the municipality. Both energy agencies have hired external consulting companies to make their energy matrixes reports.

The participants also answered a survey where they were questioned about the relevance of the proposed indicators to evaluate energy sustainability in their municipalities. The indicators that were not considered as very relevant by the local authorities are presented in Table 6. AREANATejo which has municipalities with low population density has said that the assessment of transport-based indicators was not so relevant in their context. The City of Boston has stated that the indicator which assesses active public participation in energy-related policy-making was not so relevant, once the State and Federal are the policy levels. For them, this indicator would show how active the citizens are in State and Federal policy-making. The ratio of energy-related jobs to population was pointed out by the City of Boston and AdEPorto as not very relevant. They believe that the share of energy-related jobs will be minimal and they consider difficult to define what energy-related jobs are.

The participants were also questioned about the availability of data needed to compute the indicators. The local authorities have confirmed that the data is not readily available for more than half of the indicators. There is a need to perform estimates as well as surveys to collect the data required.

However, the authors advocate that the indicators should not be removed because of data constraints or be replaced by easily measured indicators. Instead, the regular statistical data monitoring procedures should be revised in order to accommodate the needs of data for critical indicators.

The results of both components of the testing stage constituted valuable inputs in the review process of the set of indicators. This experience has validated that it is important to have a limited number of indicators, albeit comprehensive in terms of the aspects covered. Both participating and non-participating local authorities have mentioned time and staff constraints to perform the task of calculating the indicators. Large sets tend to be complex and time-consuming in computing all the indicators and this might

Table 5
Indicators calculated by the participating local authorities.

Indicators	AdEPorto	AREANATejo	City of Boston
GHG emissions from energy use, per capita and per unit of GDP	√	√	√
Primary Energy use per capita	√	√	√
Annual energy consumption per capita by main use category	√	√	√
Ratio of local renewables production to local consumption of energy and electricity	–	–	√
Ratio of energy-related jobs to population	–	–	–
Locally available finance schemes for energy efficiency and renewable energy	–	–	–
Emissions of air pollutants from road transport activities	–	–	√
Active public participation in energy-related policy-making	–	–	–
GHG emissions by sector	√	√	–
Industrial energy intensity	–	√	–
Agricultural energy intensity	–	√	–
Service/commercial energy intensity	–	√	–
Household energy intensity	√	√	–
Transport energy intensity	–	–	–
Energy consumption by transport mode	√	–	–
Modal split of passenger transport	–	–	–
Travel distance by mode of transport	–	–	–
Access to public transport	–	–	–
Fuel shares in energy and electricity	–	√	–
Renewable energy share in energy and electricity	–	–	–
Energy production from microgeneration projects	–	–	–
Share of household income spent on fuel and electricity	–	–	–
Responses to public consultations of energy-related projects	–	–	–
E-government on-line energy-related information availability	–	–	–
Awareness raising campaigns on energy issues	–	–	–
Local Authority advice and assistance to the citizens on energy issues	–	–	–

Table 6
Indicators not considered as very relevant by the participating local authorities.

Indicators	AdEPorto	AREANATejo	City of Boston
Ratio of energy-related jobs to population	√	–	√
Active public participation in energy-related policy-making	–	√	√
Modal split of passenger transport	–	√	–
Travel distance by mode of transport	–	√	–
Access to public transport	–	√	–
Responses to public consultations of energy-related projects	–	√	–

discourage local authorities. The review of the set was performed by having in mind the practical experience gained during the testing with the case study and the feedback given by the local authorities. Table 7 presents the review process, including observation notes. There were an extensive number of indicators to assess transport and public participation. The indicators were being strongly correlated, so it was decided to reduce their number by identifying the best indicators to translate local sustainable mobility and public participation in energy issues.

The revised set of local energy sustainability indicators is thus composed by 18 indicators. In the context of using the indicators in energy planning processes, it was considered a new organization of

Table 7
Review of the set of indicators after the testing stage.

Indicators	Decision on continuity	Observations
GHG emissions from energy use, per capita and per unit of GDP	√	Named 'GHG emissions from energy use, per capita and per unit of GDP, and by sector' (Households, services, industry, and transport)
Primary energy use per capita	√	–
Annual energy consumption per capita by main use category	√	–
Ratio of local renewables production to local consumption of energy and electricity	√	–
Ratio of energy-related jobs to population	√	Although there were two local authorities not considering as a very relevant indicator, it was decided to keep it based on references such as the report on the Potential Workforce Impacts of the Chicago Action Plan which estimates a generation of '2500 energy efficiency related jobs on annual basis, plus hundreds of jobs in areas such as renewable energy ...' [25]. Energy-related jobs are here defined as jobs generated in renewable energy and energy efficiency sectors in the municipality. To clarify the concept it was decided to change the name of the indicator to 'Ratio of green energy jobs to population'.
Locally available finance schemes for energy efficiency and renewable energy	√	The indicator depends on the political context, but there is plenty of room for local authorities to introduce finance schemes, such as energy performance contracting and third party financing as Bristol, Graz and Heidelberg have done [26].
Emissions of air pollutants from road transport activities	√	–
Active public participation in energy-related policy-making	√	Changed to Public participation in energy-related policy-making, including now active participation, consultation and information.
GHG emissions by sector	×	Included in indicator GHG emissions from energy use, per capita and per unit of GDP.
Industrial energy intensity	√	–
Agricultural energy intensity	√	–
Service/commercial energy intensity	√	–
Household energy intensity	√	–
Transport energy intensity	√	–
Energy consumption by transport mode	×	The calculation of the transport energy intensity requires knowing the energy consumption by transport mode. No new information will be added by keeping this indicator.
Modal split of passenger transport	×	Derived from the data used to compute the transport energy intensity.
Travel distance by mode of transport	×	Derived from the data used to compute the transport energy intensity.
Access to public transport	√	Adapted to 'Public Transit Ridership'. Access to public transport requires a more complex computing method using geographic information systems.
Fuel shares in energy and electricity	×	Derived from the data used to compute the renewable energy share in energy and electricity, and both indicators would be very similar.
Renewable energy share in energy and electricity	√	–
Energy production from microgeneration projects	×	Derived from the data used to compute the ratio of local renewables production to local consumption of energy and electricity
Share of household income spent on fuel and electricity	√	–
Responses to public consultations of energy-related projects	×	Can be assessed in the indicator public participation in energy-related policy-making, now including information, consultation and active participation.
E-government on-line energy-related information availability	×	Can be assessed in the indicator public participation in energy-related policy-making, now including information, consultation and active participation.
Awareness raising campaigns on energy issues	√	–
Local authority advice and assistance to the citizens on energy issues	√	–

Table 8
State indicators.

	State indicators	
	Indicator	Units
S1	GHG emissions from energy use, per capita and per unit of GDP, and by sector	Tonnes CO_2 eq. per capita and per Euro
S2	Primary energy use per capita	Toe (p.e.) per capita
S3	Final energy use per sector	Toe (f.e.)
S4	Ratio of local renewables production to local consumption of energy and electricity	%
S5	Industrial energy intensity	Toe (f.e.) per Euro
S6	Agricultural energy intensity	Toe (f.e.) per Euro
S7	Service/commercial energy intensity	Toe (f.e.) per Euro
S8	Household energy intensity	Toe (f.e.) per capita
S9	Transport energy intensity	Toe (f.e.) per pkm or tkm
S10	Public transit ridership	pkm per capita
S11	Emissions of air pollutants from road transport activities	Tonnes
S12	Renewable energy share in energy and electricity	%
S13	Share of household income spent on fuel and electricity	%
S14	Ratio of green energy jobs to population	%

p.e.: primary energy and f.e.: final energy.

Table 9
Policy indicators.

	Policy indicators	
	Indicator	Units
P1	Locally available finance schemes for energy efficiency and renewable energy	Qualitative
P2	Awareness raising campaigns on energy issues	%
P3	Public participation in energy-related policy-making	% or qualitative
P4	Local authority advice and assistance to the citizens on energy issues	Qualitative

the indicators: state and policy indicators. State indicators focus in assessing the physical state of the local energy system. Policy indicators aim to assess the mechanisms promoted by the local authority which may lead to the achievement of a sustainable state of the local energy system. For instance, if the local authority provides financial incentives for renewable energy, this might lead to the deployment of more renewables in the municipality, the reduction of fossil fuels consumption and consequently the reduction of GHG emissions. The previous division into core and complementary set had the disadvantage of mixing these indicators. Tables 8 and 9 present the state and policy indicators, respectively.

In order to provide a clear understanding of what the set of indicators aims to measure, Fig. 3 provides an illustrative representation of the energy chain within the Earth ecosystem and the indicators. Primary energy refers to the energy that is gathered directly from natural resources. Final energy refers to the delivered energy which is made available to the consumer, not taking transformation losses into account. Useful energy is the part of energy that is used to provide the energy service (work, heat).

The Earth ecosystem's physical limits represented in Fig. 3 are limits of the ability of Earth sources to provide materials and energy needed to keep people, factories and transport functioning, and to the ability of Earth sinks to absorb the pollution and waste [28].

4. Indicators in local sustainability assessment initiatives

Five local sustainability assessment initiatives were identified through a web search using the Google search engine and websites of projects pointed out by professionals in the field of local sustainability. These initiatives are presented in Table 10. Not all the initiatives are energy-specific, but they do contain at least a category on energy. The purpose of the initiatives ranges from benchmarking to ranking, and more recently to rating.

The Sustainable Energy Benchmark and Toolkit for Local authorities [15] covers only the activities and services provided by the local authority and not the activities developed in different sectors in the municipality territory. The Local Governments Climate Partnership Benchmark [16] provides a set of 17 indicators, from which 10 are city-wide (Table 11) and the remaining are subjected to local government activities. Initiatives like the Smarter Cities [17] and SustainLane [18] are designed by defining a matrix of criteria and scoring methodology allowing in this way to measure and compare sustainability in cities across the US. Table 11 presents the indicators that make part of the energy and transport categories of these last three initiatives. The STAR Community Index is expected to be launched by 2010 [29]. It is composed by eight committees for several categories, including Energy & Climate. The STAR Community index aims to provide a framework with indicators and metrics to assess local sustainability through a rating system [30].

When comparing the indicators employed in these initiatives with the indicators proposed in this paper, it is found that only few are common or similar. This is the case of the emissions of carbon dioxide (CO_2) per capita, the renewable energy use, the energy consumption of households and commerce, the energy conservation incentives offered and the public transit ridership. A major part of the indicators included in the initiatives are limited to counting numbers, such as the number of private vehicles, the number of green commuting options or the number of LEED buildings. Although this is easier to collect data, the point is that the data may be of limited value for local authorities. The number of private vehicles or the number of green commuting options do not inform local authorities of how much the citizens are using different modes of transport. The set of indicators included in Smarter Cities does not include the emissions of GHG or the energy used, which actually informs the local authorities about the municipality impact in climate change. It could be pointless to collect data on the incentives for energy conservation if the outcomes over time are not measured. Also, to count the cities that have signed a climate commitment does not mean that they are really implementing actions to reduce GHG emissions, nor that such actions are being effective.

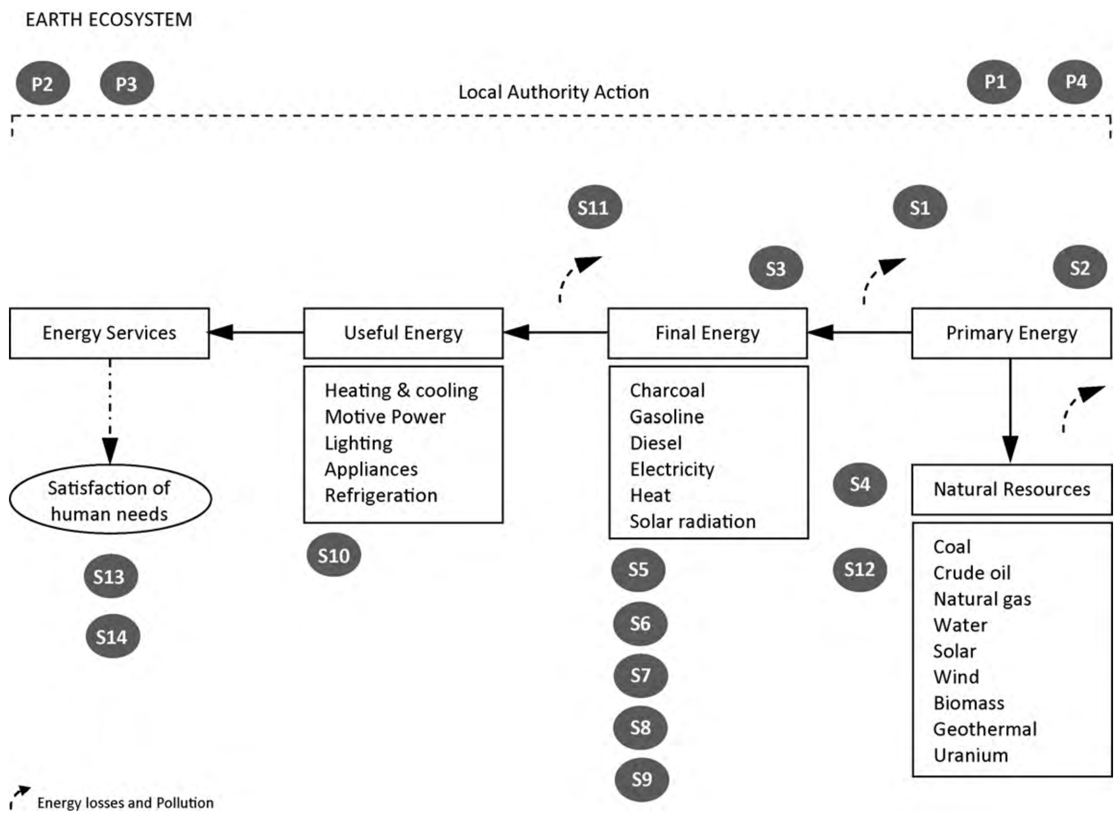


Fig. 3. The energy chain within the Earth ecosystem and the related state and policy indicators (presented respectively in Tables 8 and 9).

5. Local energy planning practices and the role of indicators

ICLEI, an international association of local governments committed to sustainable development, has developed the City Climate Catalogue [31]. In this catalogue local authorities around the world are invited to share their targets and achievements in climate action. By March 2010, almost three thousand local authorities have stated their GHG emissions reduction targets. The catalogue is here investigated to determine what steps local authorities are currently taking in local climate action. It was made an analysis of 100 municipalities from 20 countries of this catalogue (Fig. 4). The results of this analysis are shown in Fig. 5. The criterion of selection was to include a great diversity of countries, while the municipalities were selected randomly.

Fig. 5 shows that most of the municipalities have adopted a GHG emissions reduction target. Nevertheless, not all these municipalities have conducted a GHG emissions inventory. About half of the municipalities have developed a local action plan and 65% have declared that they have implemented policies and measures. With respect to monitoring, only 32% have said that they have monitored the results.

In order to have a better understanding of the role of indicators in local energy planning processes, it was decided to investigate with more detail existing local sustainable energy and climate action plans. These plans have been emerging during the last decade in response to act on climate change and sustainable energy at the local level.

The process started by identifying municipalities in the US and in the European Union (EU) with action plans. This was made through a web search using the Google search engine and websites operated by local authorities active in energy planning that were known from previous work [26]. There were identified 22 plans through this search. The selection of 10 action plans was performed by comprising five US municipalities and five EU municipalities. The scope of the analysis consisted in identifying the use of indicators in the municipalities' action plans; understanding their purpose; and matching the indicators used in the plans with the framework of indicators proposed in chapter 3. All the information was collected from the documents available in the local authority or climate program websites, such as the action plans and monitoring reports.

Table 10
Local sustainability assessment initiatives.

Project name	Scope	Energy-specific	Purpose		
			Benchmarking	Rating	Ranking
Sustainable Energy Benchmark and Toolkit for Local authorities	Activities and services provided by the local authorities in the United Kingdom	√	√	–	–
Local Governments Climate Partnership Benchmark	Cities in Germany, Japan and the US	√	√	–	–
Smarter Cities	Cities in the US	×	–	–	√
Sustainlane	Cities in the US	×	–	–	√
STAR Community Index	Cities in the US	×	–	√	–

Table 11
Energy-based indicators included in three local sustainability assessment initiatives. *Source:* [16–18].

Project	Indicator
Local Governments Climate Partnership Benchmark	CO_2 per capita Renewable energy (power) Renewable energy (heat) Combined heat and power Energy consumption of households Energy consumption of commerce Compensation measures Transport choice Private car fleet Municipal solid waste
Smarter Cities	Top three fuels used for power generation Energy conservation incentives offered Green power offered by utility Number of total LEED-certified buildings and any number of LEED-platinum buildings Any number of Energy-Star-rated buildings Use of an alternative green building certification system Sprawl reduction strategies Number of green commuting options for citizens including bicycle paths, bike sharing, bus system, carpool lanes, car sharing, dedicated bicycle lanes, light rail, park and ride, sidewalks and trails, subway, trolley and other Documented ridership for public transportation
SustainLane	City greenhouse gas tracking and carbon emission inventories Carbon emission reduction goals Overall renewable energy use Percentage for each city's alternative fuelled vehicles as part of the total vehicle fleet Cities that had formally signed onto the US Mayor's Climate Protection Agreement Number of total LEED-certified buildings Average time spent waiting in traffic Metro region public transit ridership miles and square miles per region

Table 12 presents the findings in what regards the use of indicators and the purpose of being used in the 10 action plans.

The results of the analysis have shown that indicators are employed in the diagnosis of the current situation in all the 10 plans. The indicator of GHG emissions is used in the diagnosis or GHG inventory of all plans and is also the indicator for which a target has been drawn.

With respect to the use of indicators for monitoring the target and the actions, only five municipalities specify the indicators. It was found that Cambridge [42–44], Seattle [45–47], Stockholm [49] and Barcelona [48] have been assessing the target and some actions through indicators. These indicators are found in annual monitoring reports. London has a vast number of monitoring publications, and plans to assess the progress of the climate action plan through the indicators already addressed in these publications [50–52]. For the remaining municipalities, there was not found any information available regarding the monitoring process and the indicators to be employed.

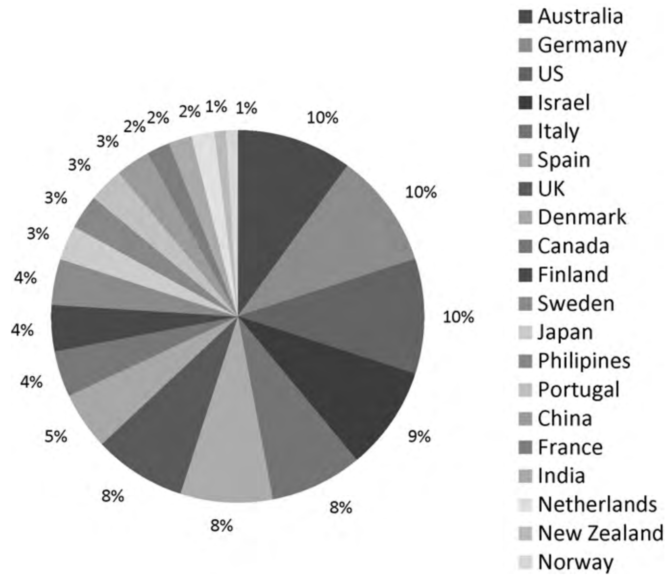


Fig. 4. Distribution of municipalities analysed per country.

Identifying and using explicit indicators as decision criteria to choose the actions to be included in the action plan is not a common practice in the action plans examined. Only Chicago has defined criteria to evaluate and choose the actions to be incorporated in the action plan. The six criteria used by the Chicago Climate Task Force are presented in Table 13. However, only indicators such as the GHG emissions and job creation are similar to the indicators proposed in this paper.

In what regards the presence of the proposed indicators (chapter 3) in the action plans, it was found that only a small number are being considered in the plans and respective monitoring reports. The findings are presented in Table 14. Nevertheless, there are some similarities in indicators such as the GHG emissions and the final energy use per sector (although not always all the sectors were considered as well as all the energy vectors). Other indicators addressed by the local authorities are the renewable energy share in energy and in electricity; the primary energy use per capita; the public transit ridership; the transport energy intensity; and the household energy intensity. Some of

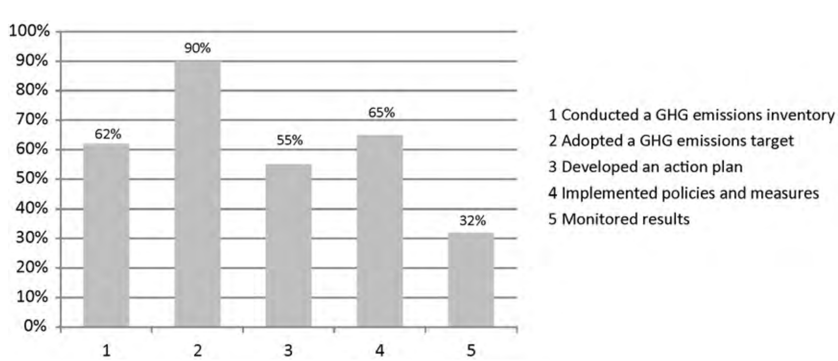


Fig. 5. Share of municipalities that have conducted each of the steps for climate action. *Source:* [31].

Table 12
Analysis of the presence of indicators in 10 energy and climate action plans and their purpose. *Sources:* Action plans [32–41] and respective monitoring reports [42–48].

Municipality	Year of plan	Purpose of the Indicators addressed			Purpose stated in the plan
		Diagnosis	Monitoring the actions	Decision criteria to choose the actions	
Cambridge, US	2002	√	×	×	Monitoring trends in community-wide GHG emissions and the results of the actions taken.
Chicago, US	2008	√	×	√	Decision criteria to choose the actions and each action should be continuously assessed and monitored.
Los Angeles, US	2007	√	×	×	Foster accountability and future action.
San Francisco, US	2004	√	√	×	Monitoring progress of emission reduction programs.
Seattle, US	2006	√	√	×	Measure progress in meeting the target and monitor progress on each of the actions.
Almada, PT	2007	√	×	×	Monitoring the effectiveness of the actions in the plan.
Stockholm, SE	2002	√	√	×	Monitoring the measures in the plan.
Barcelona, ES	2002	√	√	×	Monitoring the measures in the plan.
Venice, IT	2003	√	√	×	Monitoring the measures in the plan.
London, UK	2007	√	×	×	Monitoring the targets set in the plan.

Table 13
Chicago's evaluation criteria to choose the actions for the climate action plan. *Source:* [33].

Reduction potential	Total achievable GHG emissions reductions
Cost-effectiveness	Cost of implementation and the potential savings generated
Feasibility	Ease of achievement and potential to overcome barriers
Benefits and burdens	Advantages and drawbacks to the action, such as savings to residents, job creation and quality of life improvements
Regional impact	Level of opportunity for the larger six-county area
Rapid deployment	Opportunity to effect changes quickly

these indicators are not exactly the same but are similar, for instance municipalities are not assessing transport energy intensity but energy consumption by mode of transport. It was considered to account this as similar, once transport energy intensity requires the energy consumption by mode of transport to be computed.

After the attempt of matching the indicators this has led to the question of what other indicators were being assessed by the municipalities. Table 15 presents the remaining indicators included in the municipalities' monitoring reports.

The municipalities have identified that the purpose of using indicators would be to monitor their specific actions and the progress towards the target set. However, when thinking in the context of energy sustainability, the indicators presented in Table 8 are not sufficient to provide an overview of the behaviour and impacts of the energy system. For instance, in the case of Cambridge, the indicators do not tell anything about the way the citizens are travelling. In Stockholm, the consumption of electricity does not give information about the real impacts accounting for how the electricity is produced.

Current practices using indicators are still lacking a holistic approach. The framework of local energy sustainability indicators proposed in this paper seeks to close this gap.

Table 14
Match of the indicators proposed (chapter 3) with the indicators used by the municipalities' energy and climate action plans and monitoring reports examined. *Sources:* [32–52].

	Indicator	Ca	Ch	LA	SF	Se	Al	St	Ba	Ve	Lo
S1	GHG emissions from energy use, per capita and per unit of GDP, and by sector	√	√	√	√	√	√	√	√	√	√
S2	Primary energy use per capita	×	×	×	×	×	√	×	√	×	√[a]
S3	Final energy use per sector	√	√	×	√	×	√	×	√	√	×
S4	Ratio of local renewables production to local consumption of energy and electricity	×	×	×	×	×	×	×	×	×	×
S5	Industrial energy intensity	×	×	×	×	×	×	×	×	×	×
S6	Agricultural energy intensity	×	×	×	×	×	×	×	×	×	×
S7	Service/commercial energy intensity	×	×	×	×	×	×	×	×	×	×
S8	Household energy intensity	×	×	×	×	√	×	×	×	×	×
S9	Transport energy intensity	×	×	×	×	×	×	×	√	√	×
S10	Public transit ridership	×	×	×	√	√	×	×	×	×	√
S11	Emissions of air pollutants from road transport activities	×	×	×	×	×	×	×	×	×	√
S12	Renewable energy share in energy and electricity	×	×	×	√	×	×	×	√	√	√
S13	Share of household income spent on fuel and electricity	×	×	×	×	×	×	×	×	×	√
P1	Ratio of energy-based jobs to population	×	×	×	×	×	×	×	×	×	×
P2	Locally available finance schemes for energy efficiency and renewable energy	×	×	×	×	×	×	×	×	×	×
P3	Awareness raising campaigns on energy issues	×	×	×	×	×	×	×	×	×	×
P4	Active public participation in energy-related policy-making	×	×	×	×	×	×	×	×	×	×
P5	Local Authority advice and assistance to the citizens on energy issues	×	×	×	×	×	×	×	×	×	×

Ca: Cambridge; Ch: Chicago; LA: Los Angeles; SF: San Francisco; Se: Seattle; Al: Almada; St: Stockholm; Ve: Venice; and Lo: London.
[a] It is not specified if it is primary or final energy use [50].

Table 15
Indicators included in the monitoring reports of Cambridge, Seattle, Barcelona and Stockholm energy and climate action plans. *Source:* [42–52].

Cambridge	**Seattle**
Waste and recycling collected by City	Bike to work day participants
Total vehicle miles kilometre	Per capita vehicle miles kilometre
Vehicle registrations	Percentage of Seattle residents living in urban centres/Villages
PV installed capacity	Residential and non-residential per capita
Number of LEED buildings	Electricity and natural gas use
Purchase of green power	Per capita water consumption
Municipal vehicle fuel use	Per capita non-recycled waste
Electricity and natural gas consumption in residential, commercial and institutional	Share of waste recycled
	Number of biodiesel stations in Seattle
	Average Weekday Metro and Sound Transit Ridership
	Per capita residential electricity use
	GHG emissions by sector
Barcelona	**Stockholm**
Energy intensity	Energy source of district heating
Electricity produced in Barcelona by source	Vkm (vehicle kilometre) – transportation to work
Surface area of solar thermal installed	Use of electricity (total & capita)
Final energy use by energy sources and by sector	One person household total CO_2 emissions
GHG emissions by energy sources and by sector	*GHG emissions by sector per capita*
Renewable energy produced in Barcelona	
Primary energy use	
London	
Relative annual mean monitored pollutant concentrations	
Number of journeys and distance travelled (per person per year)	
Traffic counts at London cordons since 1990	
Passenger journeys by mode	
CO_2 emissions from transport in London by mode	
CO_2 per passenger kilometre by mode	
Carbon efficiency	
Traffic volumes (vehicle km)	
Travel to School (% walk, bus, car)	
Green Procurement Code	
Ecological Footprint	
Total energy consumption 2000–2003	
Total CO_2 emissions between 1990 and 2006	
Non-CO_2 GHG emissions per annum in London	
Energy produced from renewable sources	
No. of houses in fuel poverty in London	
Total emissions (tonnes per year) of the main air pollutants in greater London	
Trends in use of public transport	

Indicators considered for Table 7 are in italics.

6. Conclusions

The review of current energy planning practices of the 10 municipalities analysed has shown that indicators are essentially used in the beginning of the planning process to diagnose the current situation. The same happens with the setting of performance targets, such as the GHG emissions. Using indicators to monitor the targets and the actions in the plan is also a well recognized main purpose, although with less expression than diagnosis. About half of the action plans examined have produced monitoring reports.

On the other hand, indicators have also the potential to be used as a planning tool. This means that they can serve as decision criteria, e.g. in a multi-criteria decision-making process to choose the actions to be integrated in the energy and climate action plans. Assessing the effects of a set of actions in the performance of lead indicators will provide a consistent basis to select those actions which better satisfy the evaluation criteria, i.e. the most effective. In the existing action plans, it is not always clear what was the methodology adopted to select the actions included in the action plan. While San Francisco states that it has drawn its actions from several other plans for the city [35], Chicago states that has defined evaluation criteria and has chosen the actions based on that criteria [33]. The methodologies diverge across municipalities.

The analysis of five local sustainability assessment initiatives has shown that the purpose of the indicators used by them ranges from benchmarking [14,15] to ranking [16,17] and more recently to rating [30]. The indicators used account for easy-measured data, lacking to provide a comprehensive assessment of the overall impact of local energy use.

The comparison of the indicators used in the action plans and in the initiatives with the indicators proposed in this paper, has revealed that only a small number are common or similar. This shows that there are still meaningful indicators being left outside of the current planning and assessment practices of energy sustainability.

In this paper, it was proposed a comprehensive framework of local energy sustainability indicators. Such framework was built from a literature review, feedback from three local authorities and discussion with experts. The framework considers the three main sustainability dimensions: economic, environmental and social. Despite the difficulties in gathering data for the indicators at the municipal level, it is considered that the indicators are meaningful to assess energy sustainability and efforts should be made by local authorities and statistical entities to initiate processes of data collection. The framework of local energy sustainability indicators was designed to be used both as an assessment and an action-planning tool. The use of indicators as planning tools has, very likely, the potential to provide new insights to conventional energy planning processes. Projecting the future performance of indicators resulting from alternative actions will help local decision-makers choosing the most effective actions for their plans.

Acknowledgments

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